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CARDEROCKDIV-PAS-93-1 Modular Electro-Thermal Chemical Gun Power System: A Conceptual Design for Naval Platforms

Modular Electro-Thermal Chemical Gun Power System: A Conceptual Design for Naval Platforms

by
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unit is roughly half the size of the prime power unit. In order to minimize its weight and volume, the power system derives fuel (JP-5), electricity (~250KW 60 Hz AC), high pressure air (100 psi), and cooling (70 gpm freshwater @95°F) from the host ship. Additional modules could also be installed aboard ships unable to supply these auxilaries. Design issues associated with the power module, and some typical module/host interfaces are discussed. A sample module concept is presented for an aircraft carrier to bring these issues and interfaces into perspective. The power system modules are used in this case to drive two 60 mm ETC CIWS's. This configuration results in a 4 MW gas turbine driving a 10 MW limited duty cycle generator and an advanced composite flywheel. The resulting power system arrangement appears feasible for a variety of shipboard applications where autonomous combat systems power is needed for advanced electric guns.

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This report examines the development of a modular pulsed power system for installation aboard a variety of naval ships. The predominately self-contained modules are sized to power either 60 mm or 5 inch Electro-Thermal Chemical gun formats in their respective mission profiles. The design is based on shipboard requirements, and therefore represents near term goals rather than off the shelf technology. Discussion is provided concerning the relationship between an off-the-shelf design and the concept presented herein. The power system is designed to be built ashore in two units. The prime power unit contains a gas turbine, gearbox, flywheel, generator, and rectifier components. The "PFN" unit contains the Pulse Forming Network sized for the specific gun being driven. The gun and associated fire control radar are considered external components and will not be part of the power system. The prime power unit is roughly the size of a standard tractor trailer (35 ft x 8 ft x 8 ft) and may be attached to a ship in a variety of manners. The PFN unit is roughly half the size of the prime power unit. In order to minimize its weight and volume, the power system derives fuel (JP-5), electricity (~250 KW 60 Hz AC), high pressure air (100 psi), and cooling (70 gpm freshwater @ 95 °F) from the host ship. Additional modules could also be installed aboard ships unable to supply these auxiliaries. Design issues associated with the power module, and some typical module/host interfaces are discussed. A sample module concept is presented for an aircraft carrier to bring these issues and interfaces into perspective. The power system modules are used in this case to drive two 60 mm ETC CIWS's. This configuration results in a 4 MW gas turbine driving a 10 MW limited duty cycle generator and an advanced composite flywheel. The resulting power system arrangement appears feasible for a variety of shipboard applications where autonomous combat systems power is needed for advanced electric guns.

ADMINISTRATIVE INFORMATION

This report describes work performed by the Pulsed Power Systems Office, Code 272X, of the Power Systems Division, Propulsion and Auxiliary Systems Department, Naval Surface Warfare Center, Carderock Division, Annapolis Detachment. The work was sponsored by the Balanced Technology Initiative (BTI)/Naval Sea Systems Command (NAVSEA) Electro-Thermal Gun System Demonstration Program, Program Element 63737D. NAVSEA program manager is CDR C. Dampier, SEA-06KR12.

INTRODUCTION

Advanced Electro-Thermal Chemical (ETC) weapon systems utilizing "pulsed" electrical power sources are currently being developed for defense against anti-ship missile

threats. In concert with the development of the gun and cartridge technology necessary to defeat this threat, the Pulsed Power Team at Naval Surface Warfare Center, Annapolis has been tasked to study the issues associated with integration of these systems aboard a variety of ship platforms. As a part of this study, the need arose for a modular weapon/power system for ships where utilizing existing prime power would be prohibitively expensive or operationally impractical. The first candidate ship of this type was the modern nuclear powered aircraft carrier, or CVN. Prime power extraction from ships of this class was found to be impractical due to existing doctrine on the use of primary or backup power systems related to the nuclear reactor plant. One alternative was an auxiliary dedicated power plant for the pulsed weapon system. The development of a "self sufficient" weapon system was therefore initiated. It was quickly found that cost reduction favored a modular type design, which could be assembled ashore and contain minimum interfaces with the host ship. This modular approach also facilitates possible gun system transfers from ship to ship.

The objective of this report is to lay the groundwork for showing the conceptual feasibility of these concepts for ETC guns, and more specifically their pulsed power systems for shipboard applications. It is organized so that the reader may gain insight into the process of power module design by first discussing general issues, proceeding to definition of interface issues and concluding with a sample modular design.

DESIGN ISSUES

Several main driving issues influence the design of a pulsed power module for ETC gun use at sea. These issues are related to the volumetric constraints, power output requirements, and internal component size tradeoffs associated with conceptual phases of the module design. A basic architecture for the power system is assumed to be fixed for this study. This architecture was chosen to maximize power and energy density based on

component state-of-the-art. It is composed of a gas turbine, flywheel and limited duty cycle AC generator combination. The output of the generator is designed to match the Pulse Forming Network (PFN) voltage so that only rectification is needed prior to PFN charging. The PFN functions to store electrical energy prior to each shot and then discharge a pulse tailored to the specific gun cartridge launch characteristic combination. The PFN is assumed here to be capacitor-based, following the latest developments in ETC gun demonstration programs for the Navy[1]. It should be remembered however, that the intent of this paper is to demonstrate the *conceptual feasibility* of a pulsed power module utilizing the most reasonably attractive and practical architecture available. The system used here, and described below, was chosen as an architecture which has received significant review and displays promising characteristics for use aboard naval combatants. Although other architectures utilizing rotating pulse generating hardware could ultimately supersede this architecture, their suitability for Navy ETC gun application will require extensive development before evaluations can be made[2].

The layout of the power system architecture is shown schematically in figure 1. A gas turbine is used as the prime power source based on its high power density. It is coupled to both a flywheel energy storage device and a limited duty cycle generator. The generator is sized to produce power at three phase, 800 Hz, 13.8 KV rms (based on existing 60 mm ETC PFN ratings), and a current/power factor combination capable of delivering up to 1000 Amps through the rectifier circuitry. These requirements correspond to the power level required for the shooting scenarios currently considered for Navy ETC guns[3]. A circuit breaker is installed on the generator output for fault protection along with a mechanical disconnect for safe decoupling during maintenance activities. The AC power is then immediately rectified to DC. The PFN would likely be located near the gun mount to minimize transmission impedance in the very high current pulse cable. Since the gun mount may be located somewhat remotely from the prime power supply, these components

are housed in separate containers. For arrangements planning, the PFN model was configured from 2 MJ capacitor banks with an assumed energy storage density of 3 J/g and 0.4 MJ/m^3 based on near term figures being used by the pulsed power community. Potential increases in the propulsive efficiency of the gun cartridge may result in up to 50% reductions in required PFN energy per shot. Advances in PFN miniaturization could reduce the size of this unit by 33 to 50% in ten years under a program currently being funded by the US Army. These reductions will filter up the power train to also reduce the required generator and flywheel ratings. Details of the PFN sizing can be found in reference 3.

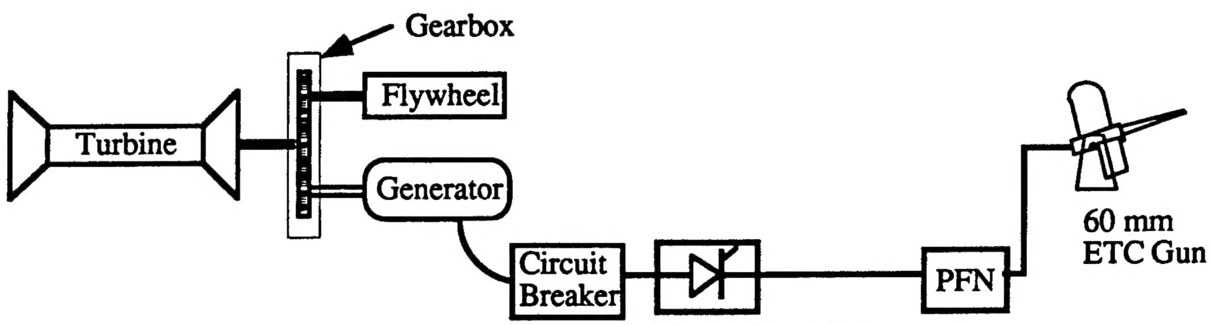

Figure 1 - Power System Architecture

VOLUMETRIC CONSTRAINTS

Because the pulsed power module is intended to be rather mobile, its components should be sized and arranged such that they may be fit into containers transportable by truck, and loadable aboard ship with "Container" cranes. The typical dimensions of these containers is up to 40 ft long, 9 ft high, and 8.5 ft wide (12 m *x* 2.7 m *x* 2.6 m). The prime power components: (gas turbine, gearbox, flywheel, generator, and rectifier) would most likely be grouped in one of these containers. This allows an output of high voltage DC to an additional container housing the PFN.

The PFN container would require less volume than the prime power container, though its width and height dimensions should remain the same to simplify handling requirements. Weight is always a concern aboard ships and its minimization is an issue. At the time of this writing, the state of technology development for many of the components is insufficient for an accurate weight minimization endeavor. However, a weight estimate is given later for a sample modular system to establish some baseline goals upon which to improve and build design guidelines.

To complete the ETC CIWS system, the gun mount and target tracking equipment must be included. Several tracking systems are currently being investigated for use with the ETC CIWS including "Target Acquisition and Ship Defense" (TASD) and Electro-Optical (EO) trackers. The electronics associated with TASD occupy a volume equivalent of two 19" equipment racks. EO trackers are composed of a camera and a PC sized computer. The receivers for each of these systems would likely be integrated into the gun mount as long as it is sufficiently high above the sea surface to provide the required tracker resolution. The ETC CIWS gun mount will be designed to utilize existing Phalanx positions aboard Navy ships. The accommodation of a modular gun mount in a mobile container has yet to be investigated and will not be considered here. Preliminary evaluations suggest that the mount/tracker combination may require a specifically designed container of different dimensions than those of the other containers. The only impact however of a special container would be the inclusion of necessary adapter hardware to allow handling by standard container cranes and trucks.

GUN POWER REQUIREMENTS

The pulsed power module being studied here is conceived in support of ETC guns for CIWS defense. *(Note: comments are also provided near the end of this report for a 5 inch gun demonstrator)*. A 60 mm CIWS ETC gun design is currently being developed as

a proof of principle demonstrator by the US Navy at FMC. Figure 2 shows an illustration of this gun. The 60 mm cartridge being developed has a design requirement of

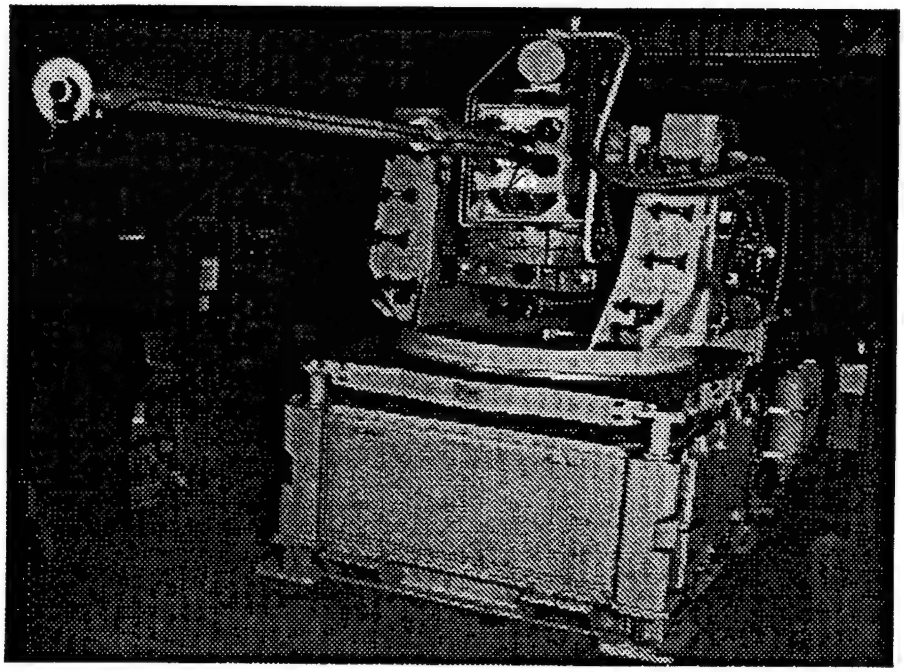

Figure 2 - FMC 60 mm ETC Gun

2 MJ stored electrical energy per shot. Contractor proprietary experiments being conducted in this development, suggest the possibility of up to 50% reduction of this electrical energy requirement. Although several operational scenarios for a ship defense gun of this size are under investigation, this report uses the following as a nominal standard:

a) 10 shot bursts at firing rate of 4 shots/second

b) at least 5 second "rest" time between bursts

c) 10 bursts per engagement

d) engagement time of 1 hour

This standard was derived from the worst case of several engagement scenario studies conducted at NSWC Dahlgren. This scenario represents the firing of up to 100 shots in a one hour period. These shots can be distributed throughout the hour, but the worst case scenario from the thermal perspective involves shooting all 10 bursts within the minimum

amount of time (70 seconds). This scenario causes component temperatures to rise to their highest levels because a minimum amount of time for conduction and convection of heat from these components has occurred. Since little time for spin-up is allowed between bursts in this scenario, the flywheel/generator speeds do not recover to pre-burst values. This results in the lowest overall speed condition after the last burst. This lowest speed must be used in the generator design to insure that adequate charging characteristics are maintained throughout the engagement.

In the next section, the impact of variations in key scenario parameters on sizing the power module will be investigated.

PRIME POWER/ENERGY STORAGE SIZING

A pulsed power module's design is highly dependent both on the average power consumed by the gun and the operating scenario. Energy storage devices can greatly reduce the required prime power with resulting reductions of:

1. required equipment volume/weight
2. fuel volume/weight
3. thermal signature
4. noise generation

This section examines the tradeoffs in prime power and flywheel energy storage sizing required to meet a variety of shooting scenarios. A flywheel was chosen for energy storage based on its high energy density. The desired goal is therefore to minimize both the gas turbine power (size) and the flywheel energy (size) for the range of operating scenarios expected for the guns. To evaluate the feasibility of various power/flywheel combinations, a simulation spreadsheet was created. The basic concept behind the simulation is the conservation of energy for the complete power system and gun. Energy is created at the rate defined by the power level of the gas turbine. Energy is consumed by each shot of the

gun (each burst of shots is modeled in proper time sequence). And energy is lost by windage and bearing friction in the gearbox, generator, and flywheel.

Because this is a preliminary feasibility study, certain simplifications have been made in the modelling of each of the energy flow processes to allow basic characteristics to be highlighted without an inordinate amount of complexity. The gas turbine is assumed to initially produce power at 10% of its rated value. This low value models the gas turbine condition prior to shooting where its only load is the windage and bearing loss torques of the flywheel/gearbox/generator. The dynamics of throttle opening is modelled by raising this power level to 40% after the first burst of shots, 75% during the second burst of shots, and finally to full rated power after this second burst. Figure 3 shows a plot of this power ramp-up as a function of time for the baseline shooting scenario. The generator is assumed to operate with an efficiency of 85%. This implies that if 2 MJ of stored PFN energy is required per shot then 2 MJ / 0.85 = 2.35 MJ of shaft energy must be delivered to the generator. The simulation calculates the total stored kinetic energy in the system at the beginning and end of each burst, and determines the associated shaft speeds. The criteria for an adequately sized system is defined by maintaining shaft speeds above a critical value related to the generator's ability to produce high voltage. Sensitivity

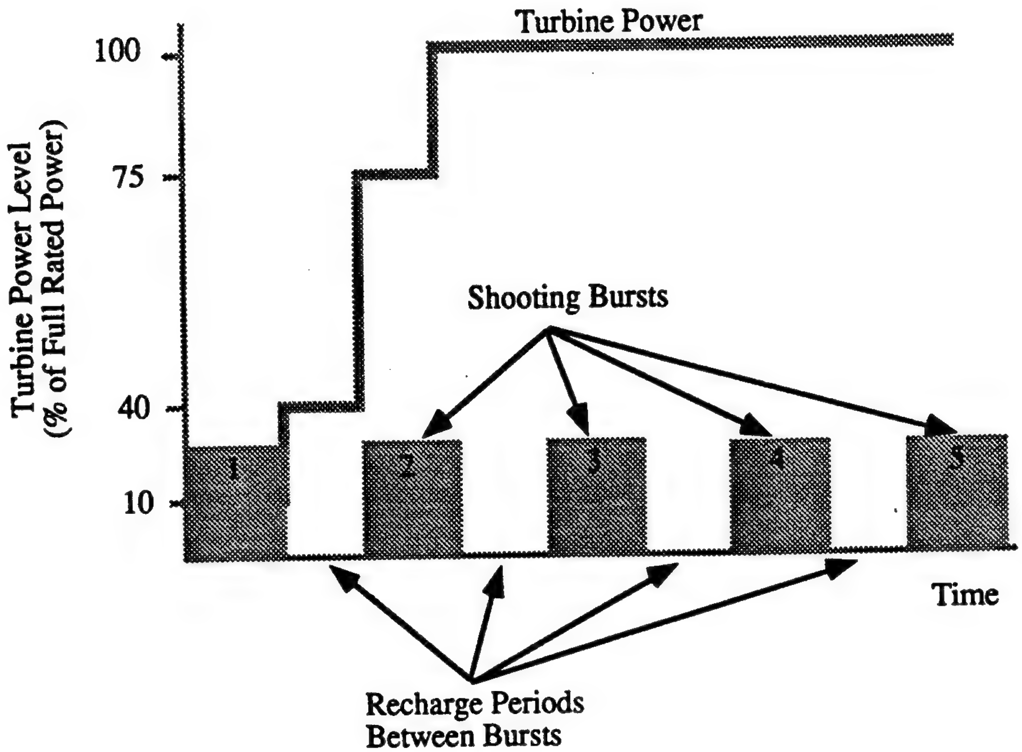

Figure 3 - Turbine Power Ramp-Up

to this critical speed is also investigated. The flywheel is modelled as an advanced composite structure with fiberglass and carbon fiber bands. The outer band of graphite fiber occupies space between 88 and 100% of the overall rotor radius. This band covers a glass fiber band occupying space between 50 and 88% of the overall rotor radius. The rotational inertia of an inner steel shaft and band support structure is considered negligible for this study.

Common vs Separate Generator / Flywheel Shafts

An important consideration in the configuration of the turbine/generator/flywheel is whether the generator and flywheel are mounted on the same shaft or separately driven as shown in figure 4. Although the separate shaft configuration allows each machine to operate at speeds commensurate with its maximum rotor tip speed limitations, it requires a

more complex gearbox. A first series of simulations were conducted to evaluate the performance penalties of common shaft operation. The constraints used for tip speed limitations were 150 m/s for the generator and 800 m/s for the flywheel. Typical rotor diameters for the generator and flywheel were 0.5 m and 0.75 m respectively. The large difference in allowed tip speed however required that the generator/ flywheel combination rotate at the generator's maximum speed, preventing the utilization of large quantities of stored energy only available when the flywheel turned at higher speeds. To illustrate this, a case was run with an 8 MW gas turbine, 10 burst scenario, 10 shots/burst, 5 sec rest time between bursts, and 2 MJ energy per shot. Unless noted, the firing rate for the gun is 4 shots per second. The critical speed for generator operation was selected at 85% (a lower limit). The flywheel rotor length required for the separate shaft configuration in this scenario was 1.4 m. In contrast the required rotor length for the common shaft case was 17 m! The rotation speed of the flywheel in each of these cases was 20,400 rpm (separate shaft) and 5600 rpm (common shaft). If the flywheel and generator are run on the same shaft and flywheel diameter varied to maintain tip speed, a 2.7 m diameter flywheel disc of 2mm thickness results. The impracticality of these large flywheel designs for a modular system suggests that the separate shaft configuration be pursued exclusively.

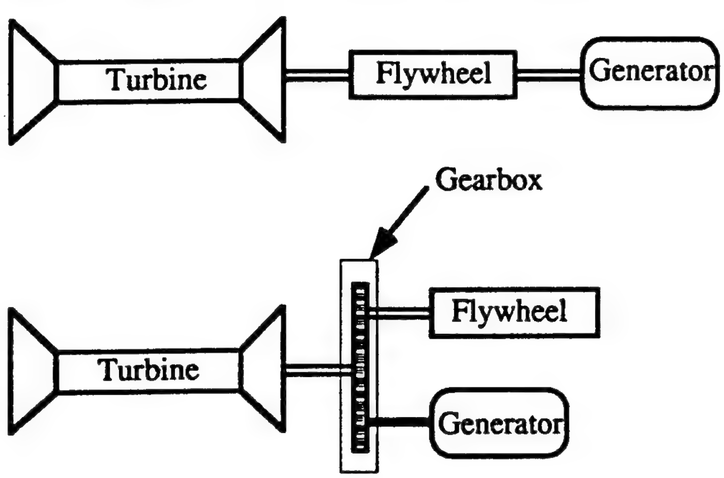

Figure 4 - Flywheel/Generator Shafting Arrangements

Flywheel Diameter and Critical Speed Reduction

The first parameters to be investigated in the power / flywheel size tradeoff were the flywheel rotor diameter and the critical speed reduction allowed on the generator. Increasing the flywheel diameter reduces both the required rotor length and rotation speed for a given tip speed. Reducing the critical generator speed allows more energy to be extracted from a flywheel of given size. Figure 5 shows the relationship between flywheel length and turbine power for variations in both the flywheel rotor diameter and critical speed reduction. In these plots one is looking for the "knee" in the curve. To the right of the knee, the flywheel size is reduced only with large increases in turbine power. To the left of the knee, the turbine power can be reduced only with large increases in flywheel size. The knee gives some indication of an optimum combination of flywheel and turbine sizes for minimum overall system size. From this graph, one can see that reductions in

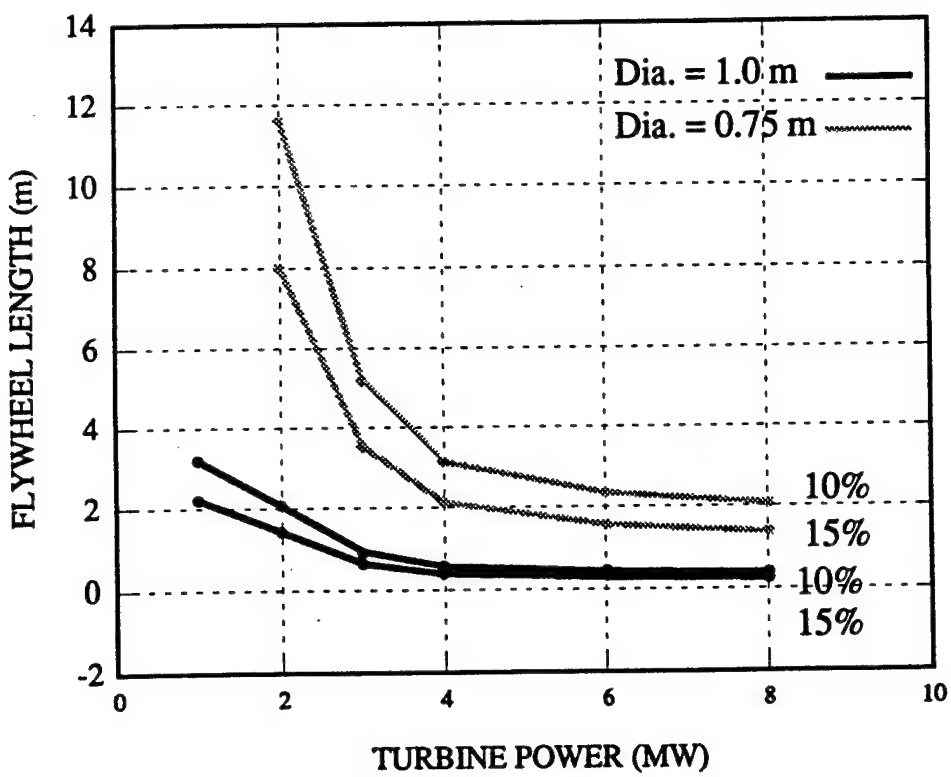

Figure 5 - Flywheel Diameter and Critical Speed Variation

flywheel diameter carry large penalties in required power and flywheel length. Critical speed specification can also be noted to have a greater impact on system size as the flywheel diameter is reduced.

Burst Number and Shots/Burst

In this section the shooting scenario is examined to determine its impact on the power /flywheel sizing tradeoff. Two variables are adjusted reflecting two characteristics of a given scenario. The number of bursts reflects the number of target threats required to engage in a given engagement. Burst numbers of 6, 8, and 10 are examined in this section. The number of shots per burst reflects a combination of the probability of kill of each shot, and the number of targets grouped together in each attack of the engagement. Bursts of 6, 8, and 10 shot clusters are studied here.

For both of these variable sensitivity tests, a flywheel diameter of 0.75 m, and a critical generator speed of 90% are assumed for these comparisons.

Figure 6 shows plots of the required flywheel length vs turbine power for variations in the number of shots fired in each burst for a ten burst engagement. As the number of shots is reduced from ten to 6 per burst, the knee moves from approximately 3.5 to 2.5 MW turbine power. This trend becomes less pronounced as the required energy is reduced as shown in the darker lines.

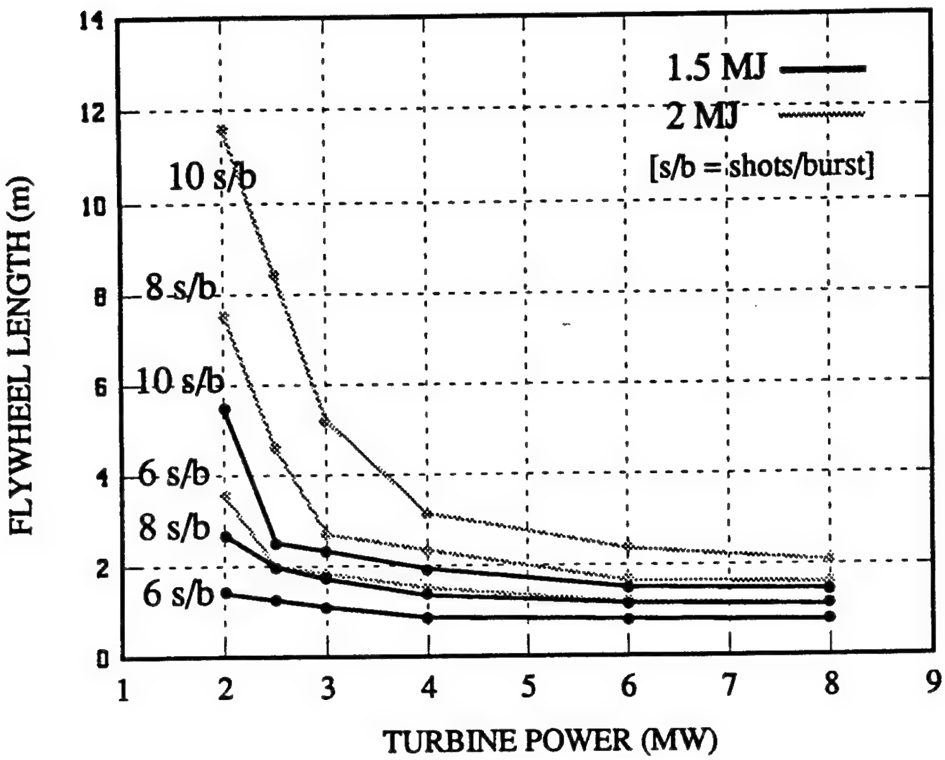

Figure 6 - Shots Per Burst Variation

Figure 7 shows the same form of plot for variations in the number of bursts per engagement. The knee in these cases occurs between 3 and 4 MW of turbine power for flywheels with diameters in the range of 0.75 to 1.0 meters in diameter.

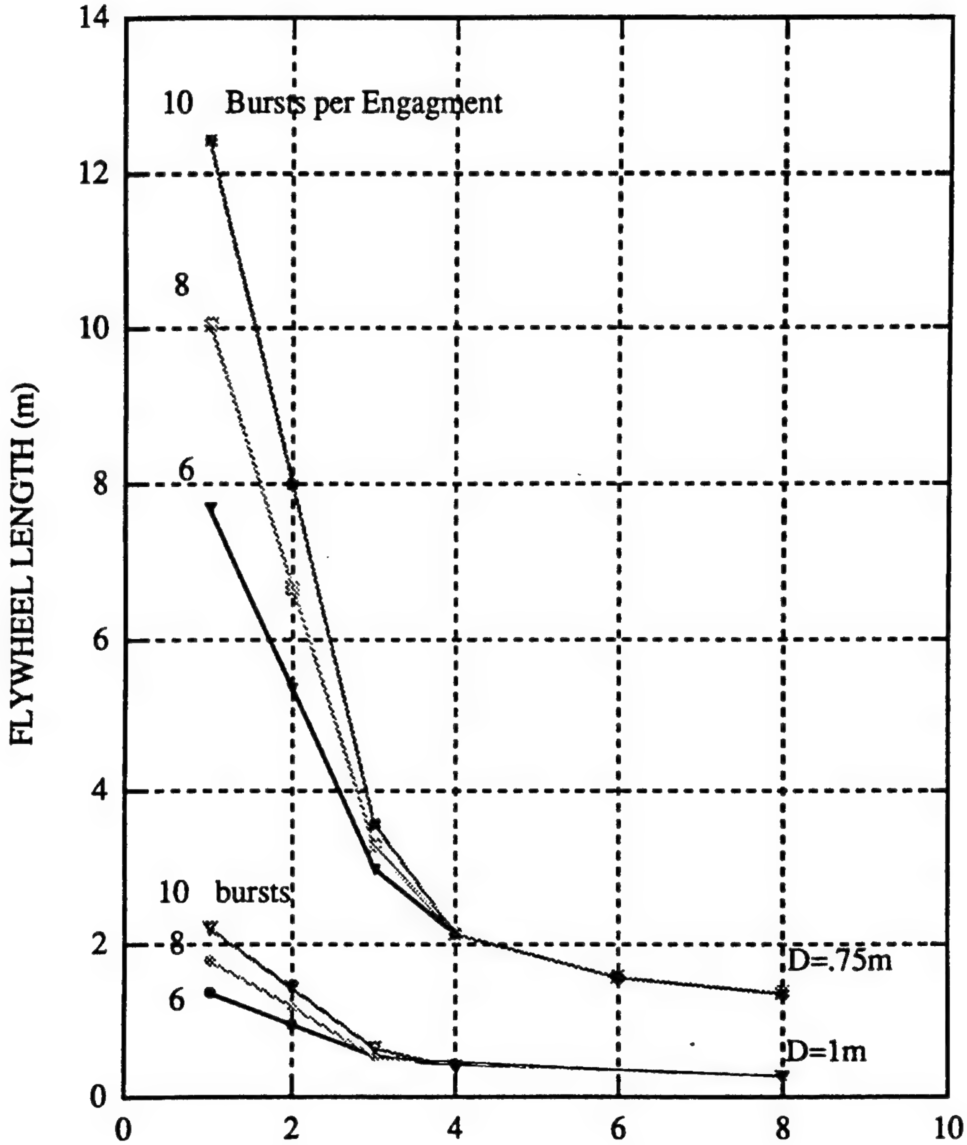

Figure 7 - Bursts Per Engagement Variation

Energy Stored Per Shot

Because current cartridge development shows promise for decreasing the required electrical energy per shot, this important variable was also examined for its influence on the power / flywheel size tradeoff. Comparisons of system sizes for PFN energy storage of 2

MJ, 1.5 MJ, and 1 MJ are shown in figure 8. Flywheel diameter is fixed at 0.75 m, and a critical generator speed of 90% is assumed for these comparisons. Drastic reductions in flywheel size can be realized by these changes, as one would expect by the corresponding reduction in electrical power consumed by the gun. The knee of the curves also varies from 3.5 down to around 2 for the reduction in cartridge electrical energy from 2 to 1 MJ respectively.

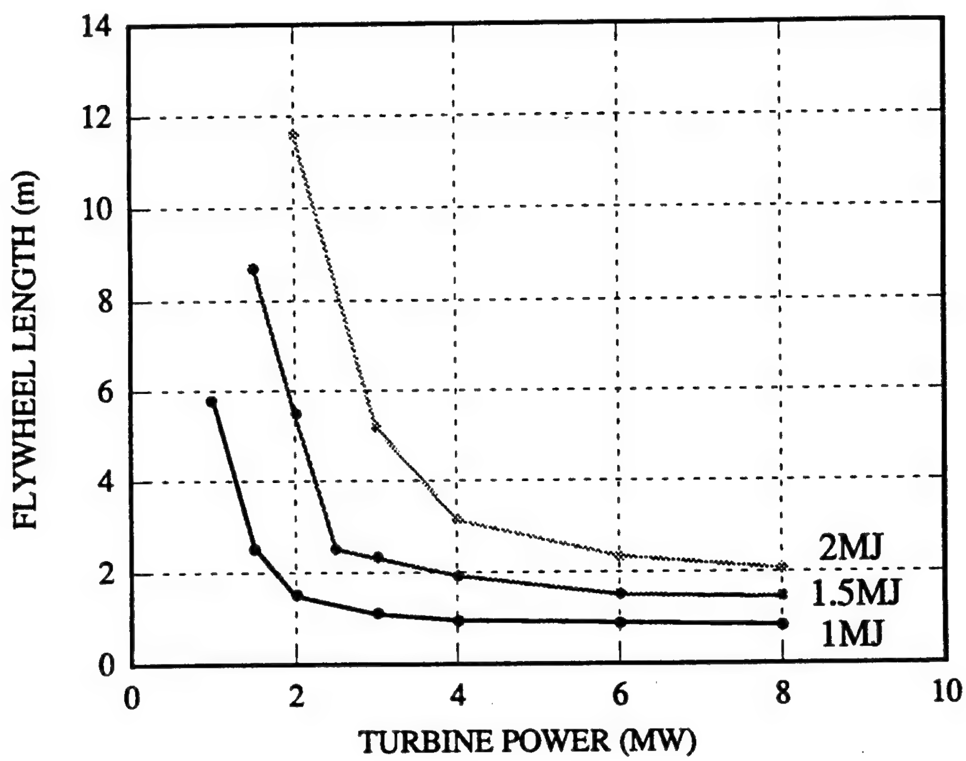

Figure 8 - Energy Per Shot Variation

SHIP INTERFACES

ARRANGEMENTS AND INSTALLATION

The power system module is designed to minimize both weight and volume. Because the module can be retrofit to existing ships, it is not likely to be placed low in the ship where large spaces are already heavily utilized. Higher placement imposes stronger

constraints on the module weight due to the increased impact on ship stability. Volume constraints are derived from both: a) deckspace limitations aboard most naval ships, and b) radar cross section reduction efforts currently being pursued.

The specific arrangements of a pulsed power module will vary significantly among different host ships, and must be examined on a case by case basis. Current studies of arrangement for the CVN (aircraft carrier) and LHD (amphibious assault ship) are being conducted, and will be described in a separate report. Typical options for arrangement include module attachment to the sides or transom of the ship, insertion into storage spaces adjacent to the exterior, or a simple deck attachment. The choice of location for the power module must take into account the interface needs for each host ship/module combination, and the normal operation of existing equipment aboard the host ship.

The prime power module should be oriented on the host ship such that its turbine/flywheel/generator rotation is aligned with the ship's fore and aft axis. This orientation minimizes the gyroscopically induced forces from roll motions of the ship. Pitch motions are still coupled with the rotational motion, but are an order of magnitude smaller than roll. Dynamic forces developed at each end of a properly mounted generator would likely be less than ± 1 kN (225 lbs) in an application aboard an aircraft carrier operating in sea states between 4 and 5.

The ducting of air to and from the gas turbine is also a prime consideration in locating the prime power module aboard the host ship. Inlet and exhaust air runs should be kept as short as possible to maximize power and efficiency in the turbine. More difficult, in many cases, is the disbursing of the hot exhaust without adversely impacting operations on or near the deck. Careful aerodynamic studies will be required in any application to verify that exhaust will not sweep around and over the ship in areas which are manned or contain temperature sensitive equipment.

An important aspect to the power module concept is that the module is built up as a

complete unit on shore before being attached to the ship. This allows efficient and accurate assembly of many of the components in an efficient work environment as opposed to onboard the ship.

FUEL

Fuel for the power module gas turbine is expected to be supplied by the host ship. Quantities of fuel are dependent on the estimated "time of operation" between refueling. For the purpose of this report, a sample scenario is used to estimate a typical fuel load required for a single power module fitted aboard an Amphibious Ship.

A representative day for the power system during an amphibious assault mission is assumed here to consist of 23 hrs in on-line standby mode, and one hour at full power shooting mode. A fuel consumption rate of 800 lbs/hr[4] (10% loading of 3.4 MW gas turbine) is assumed for standby mode and 2500 lbs/hr[4] for full power operation. This results in a daily consumption of 21,000 lbs. The JP-5 capacity of the LHD is 400,000 gallons, or 3.3 million lbs. The impact of the pulsed power system is therefore negligible since daily consumption is only 0.6 percent of capacity.

ELECTRICAL POWER

The power system module will require electrical power for pumps, lighting, and control systems. This electrical demand would be composed of both 440 volt (for the gun motor drive) and 110 volt lines. These requirements are well within margins for most ship service electrical systems.

THERMAL MANAGEMENT

Shipboard integration of any power system requires consideration of its impact on the cooling capacity of the ship. For a single Allison 501 gas turbine application, the oil cooler

would be sized for 1500 BTU/min. The gearbox and generator oil coolers can be conservatively sized at twice the typical Allison 501K specification due to the doubling of output power during brief engagement duties. The resulting lube oil systems have no separate coolers but have storage tanks of 50 gallons (for the generator) and 150 gallons (for the gearbox). The gearbox lube oil tankage is rather large in this case, and could be reduced to 75 gallons with the addition of a cooler. The prime power enclosure will require a fan capable of delivering approximately 9000 cubic feet per minute of exterior cooling air. Cooling water is expected to be supplied by the host ship for dissipation of transient heat loads from the generator, rectifier, and PFN. Conservative initial estimates of the heat rejection rates of these components during firings total approximately 5000 kW[3]. An intermediate heat storage system will be required to allow the total energy accumulated over the short firing duty cycle to be convected to ship supplied fresh water during the relatively long rest periods between firings. Utilizing the worst case firing scenario previously presented, we find a duty cycle of roughly 1/60, indicating approximately 100 kW of heat load on the ship coolant. For a 10°F temperature change in this fresh water, an estimated pumping capacity of 75 gallons per minute will be needed for the complete power system. Of this capacity, roughly two-thirds would be directed to the Prime Power container, and one-third for the PFN.

CONTROL, MONITORING, AND DIAGNOSTICS

Integration of the pulsed power system into the complete combat system requires a careful control and monitoring scheme. This scheme is heavily dependent on the radar and fire control systems available aboard the host ship. Typical control interfaces between the host ship and the power module will include command lines for charger operation (charge, shed load, shut down), and turbine/generator operation (start-up, shut-down, cruise, precharge, postcharge). In addition, a power system monitor, located internal to the

module, should interpret the array of component state measurements and output status and diagnostic signals to the host ship. A remote shut down capability must also be included in the event of monitor interruption. These interfaces could conceivably be incorporated into the host ship's auxiliary machinery monitoring system to reduce additional manning requirements. In the case of the CVN, communication lines between the existing Phalanx mounts may possibly be utilized for gun operation control.

ELECTRO-MAGNETIC INTERFERENCE

Electro-magnetic interference from the pulsed power system must be minimized from the generator, rectifier, and power transmission stages. The fundamental frequency in the generator is 800 Hz. For three phase full rectification, the dominant frequency component of the DC ripple will be near 2.4 kHz which will be shielded in the transmission cable. The entire prime power module is expected, in the militarized version, to be capable of shielding any remaining EMI after individual components have been treated. A study is currently being funded under the Navy's 6.3 program to determine the design guidelines and some preliminary configurations for the transmission system between the rectifier and the PFN. EMI considerations will play an important role in this study.

The spark gap switches traditionally used in the pulse forming network are a major source of radiated noise. These switches, combined with the large capacitors and air core inductors are capable of radiating fields at high frequencies. Although much research is ongoing in the development of low EMI alternatives to spark gap switches, it is anticipated that the entire space for the PFN will require shielding to meet mil spec standards. This approach will require special attention, however, in the design of interfaces with the cooling and ventilation systems.

AUXILIARY SYSTEMS

In addition to the main power system, auxiliary systems are necessary for safe and efficient operation. Several of these auxiliary systems are listed below.

The main power system must include a self-contained fire suppression system. This system could consist of Aqueous Film Forming Foam (AFFF), or the new mist fire extinguishing systems presently being developed by the Navy.

The gas turbine compressor would also require a wash/rinse system for periodic cleaning. For an Allison 501 gas turbine, this system would likely consist of a 10 gallon storage tank, 5 gal/min pump, 3/8 inch hoses and spray nozzles located in the air plenum chamber. The storage tank would be filled when necessary from the host ship's fresh water supply.

Although not a "system" per se, maintenance and spare parts provision must be included in a ship impact assessment of any gun/power system equipment arrangement. Regular shipboard maintenance is expected to be minimal and should be carried out on components while mounted in their respective modular containers. Substantial maintenance could more easily be performed on the module or its components on shore by removal of the container. This implies that the attachment method chosen for the container to the ship should be guided by removal requirements expected at each ship overhaul.

SAMPLE MODULE FOR CVN TRANSOM

With the previous discussion of design issues and constraints in mind, a sample pulsed power module has been conceptually designed to show how all of these factors can play together for a complete system. This sample also represents a realistic target for some of the components' development efforts. As this preliminary concept is described, notes will be made of areas where improvements must be made to enhance feasibility.

LAYOUT

The layout of the main machinery components can be seen in figure 9. A 4 MW gas turbine is chosen here, coupled with a 3 ft (0.9 m) diameter composite flywheel of 1.5 ft (.45 m) rotor length. These figures assume a 20% speed reduction over the engagement. The resulting flywheel speed is 16000 rpm. The overall dimensions of the flywheel housing (necessary for windage reduction, braking, and containment) are estimated by increasing the rotor dimensions by 33% radially and 20% axially. Limited Duty Cycle (LDC) Generator dimensions (4 ft x 1.8 ft, or 1.2 m x .54 m) allow space in the power system container for maintenance and service. External doors in the container housing would also provide access to the outboard side of the generator and both sides of the gas turbine. Access panels in the gearbox housing and container walls allow for inspection of its internal parts. The circuit breaker box is located immediately adjacent to the generator output leads, with rectifier units installed overhead in the container. Chilled water or seawater input lines would interface with the container for generator and rectifier cooling at points isolated from the electrical and fuel interfaces.

The structural base would extend from the gas turbine mounts to the generator and flywheel mounts for the purpose of maintaining good shaft alignment. Some noise isolation material would nevertheless be needed at each mount to the base. The external skin of the container could be much lighter in construction to save weight. To reduce gyroscopic forces due to ship motions, the prime power module should be oriented in the ship with its rotating componentry aligned with the fore and aft axis of the ship. The influence of roll motions in the ship will thus be minimized. The inlet and exhaust for the gas turbine will be minimized and result in minimal impact on ship operations by ductwork directed aft as is currently done at the transom Jet Engine Test Stand.

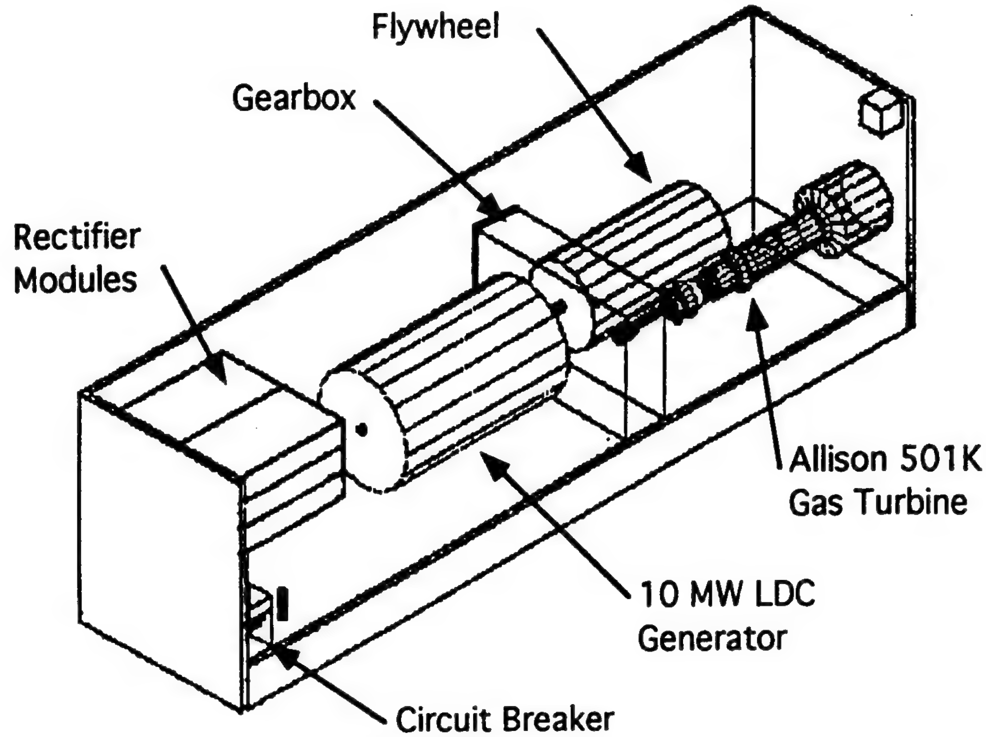

Figure 9 - Conceptual Layout of Modular Power System for Dual CIWS Application

A separate container of reduced size would contain the PFN modules required for each of the gun mounts. These PFN containers could be placed near the main power container to allow cross connecting for redundancy.

An overall weight estimate for this power module is given in the table below:

Prime Power Component Description	Weight (lbs)
501 KB Gas Turbine	2,500
Container Structure	5,000
Main Gearbox	5,000
10 MW Limited Duty Generator	4,000
Structural Base	10,000
Flywheel	6,000
Diesel/pump/aux gen	4,000
Misc Mounts	1,000
Misc Systems: Elec/Fire Prot./ Pumps/etc	4,000
Totals	41,150 (~18.5 tons)

COMMENTS ON 5 INCH ETC GUN DEMONSTRATOR

As part of a program to demonstrate the feasibility of 5 inch ETC gun technology aboard naval combatants, an Enhanced Advanced Technology Demonstrator has been proposed by the Navy. The final phase of this EATD could include the at sea demonstration of the gun aboard a test ship such as the ex USS Decatur. The main differences in the power system design in this case are the sizes of the flywheel, generator, and PFN. These components can be reduced in size due to the lower power duty cycle to be used in the demonstration program. Component size reduction permits a cost savings over fully rated componentry while also reducing developmental risk associated with their prototype nature in the demonstration. Figure 10 gives an impression of the power system layout expected for the 5 Inch ETC Gun Demonstration Program.

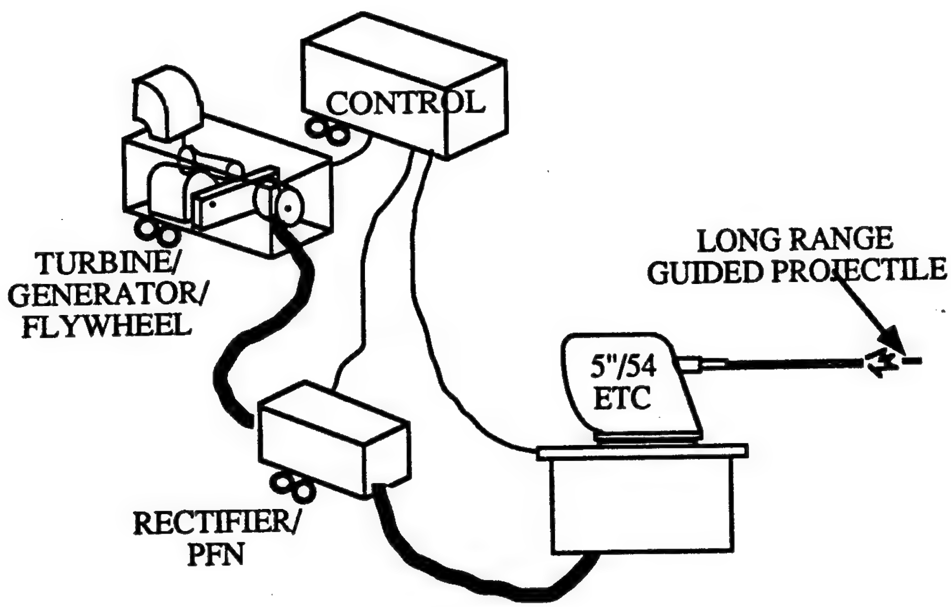

Figure 10 - 5 Inch ETC Gun Demonstration Power System Concept

The duty cycle expected in the EATD would consist, in the most demanding case, of three shots at a repetition rate of 40 rounds per minute. The stored electrical energy associated with each shot is expected to be 3 to 5 MJ. Assuming a PFN charging

efficiency of 70%, the average power draw during this burst would be 4.7 MW. If the flywheel is driven by a standard Allison 501K at a power level of at least 2 MW (fully rated power is 3 MW), the energy drawn from the flywheel is (4.7-2)MW x 4.5sec = 12.4 MJ. The total energy stored in the flywheel for a 15% speed droop over this three shot burst would be 45 MJ. This size flywheel could be sized with a rotor length and diameter of 0.9 m and 0.45 m respectively at a nominal speed of 12,000 rpm. The resultant tip speed is below 600 m/s which is well within the state-of-the-art in flywheel design.

The internal layout of the prime power module would be very similar to that described for the CIWS application above. The notable difference would be in the size of the flywheel, and the details of the generator. The baseline demonstrator generator will be an off-the-shelf (low risk) design capable of meeting the firing requirements. In addition, a limited duty cycle generator will be designed, built, and tested in the same power system. This limited duty cycle design serves as a proof of concept for its reduced weight and volume benefits. Measurements of thermal characteristics of all of the power system components during testing will enable the refinement of design guidance for militarized power system development.

CONCLUSIONS

The benefits of ETC gun technology for the future Navy are critical to defeating the advanced airborne threats expected. In addition, the higher kinetic energies obtainable with ETC gun technology will enable greater range for shore bombardment missions. The preliminary design of an ETC guns/power system module for use aboard a variety of naval vessels has been studied here.

The volume, gun power, and prime power/flywheel sizing tradeoff design issues associated with integration aboard ships highlights the magnitude of gun operation requirements on the modular power system implementation. These requirements have the

most fundamental impact on the size tradeoff between the prime mover (gas turbine) and the flywheel. Potential reductions in the required power per shot show strong influence on both sizes in the final analyses. Also to be considered under these conditions is the potential reduction in generator ratings, and associated thermal management equipment.

The variety of ship interfaces involved with the power system have been outlined in this report, and the most critical are the thermal management, EMI, and control lines. On large ships like the CVN and LHD, the fuel load is insignificant compared to the fuel storage capacity. Auxiliary electrical power can also be accommodated within existing large ship margins. The details of control system interfaces are currently being investigated, and will likely involve semi-autonomous operation with minimal direction from the host ship. EMI will be shielded in the transmission cables and in the PFN modules. Details of the EMI shielding will be addressed as the components in the PFN becomes more refined in its militarized configuration.

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